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Dilepton asymmetries at B factories in search of $\Delta B = -\Delta Q$ transitions

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In order to detect the possible presence of $\Delta B = -\Delta Q$ amplitudes in neutral B meson decays, we consider the measurement of decay time asymmetries involving like-sign dilepton events at the B factories.

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Bottom meson decay is a promising place to look for CP violation outside the neutral kaon system. It will also facilitate a test of the CP violation mechanism of the standard model [1]. One way to achieve this aim would be to measure decay time asymmetries at the asymmetric B factories presently under construction [2]. But violations of the standard model may show up in B physics in other ways also. Here we focus on the interesting possibility of the breakdown of $\Delta B = \Delta Q$ rule in semileptonic decays of neutral bottom mesons. This rule is not exact as it is violated in higher order weak interactions. For instance, a $\Delta B = -\Delta Q$ amplitude is generated in the decay $B(\bar{b}d) \to \pi^+ e^- \bar{\nu}_e$ by two tree-level transitions $\bar{b} \to \bar{q} u \bar{d}$ and $d \to q e^- \bar{\nu}_e$ by exchanging the quark $q = u, c, t$. However an estimate of this amplitude may be misleading because we could have additional contributions (at the same order and with the same CKM factors) from the $\bar{b} \to \bar{d}$ Penguin transition, and the effects due to new particle exchanges in the Penguin loop are unknown [3]. In any case, an experimental check of the $\Delta B = \Delta Q$ rule as a phenomenological question is important in its own right; the rule forms the basis of lepton-tagging of bottom flavor. For this check, we shall examine the decay time asymmetries involving like-sign dilepton events produced at asymmetric factories of $\Upsilon(4S)$.

The parameters of interest are the ratios of semileptonic decay amplitudes for B and $\bar{B}$ mesons

to decay into the channels $h_i \ell^+ \nu_\ell$ and the conjugate channels $\bar{h}_i \ell^- \bar{\nu}_\ell$:

$$r_i \equiv \frac{q}{p} \frac{< h_i \ell^+ \nu_\ell | T | \bar{B} >}{< h_i \ell^+ \nu_\ell | T | B >} \ , \quad \bar{r}_i \equiv \frac{p}{q} \frac{< \bar{h}_i \ell^- \bar{\nu}_\ell | T | B >}{< \bar{h}_i \ell^- \bar{\nu}_\ell | T | \bar{B} >} \ . \tag{1}$$

Here h_i stands for a single hadron $h_i = D^-, \ D^*(2010)^-\ ,\ \rho^-\ ,\ ...$; the constants p and q define the usual time-propagating states $B_{1,2} = pB \pm q\bar{B}$ with masses $m_{1,2}$ and widths $\Gamma_{1,2}$. We assume complete CPT invariance throughout, which implies the following relations amongst the amplitudes

$$\begin{aligned} < h_i \ell^+ \nu_\ell | T | B > \quad &= \quad < \bar{h}_i \ell^- \bar{\nu}_\ell | T | \bar{B} >^* \ , &(2)\\ \bar{r}_i \quad &= \quad \left| \frac{p}{q} \right|^2 r_i^* \ . &(3) \end{aligned}$$

Note that there is no ‘strong phase’ due to final state interaction as we are restricting ourselves to semileptonic channels containing a single hadron (the tiny phase shift due to electroweak scattering is ignored). The complex parameters r_i and $\bar{r}_i$ vanish if the standard model rule $\Delta B = \Delta Q$ holds.

We concentrate on the exclusive semileptonic decays of the two *neutral* B mesons emitted by $\Upsilon(4S)$ produced at a B factory. Let $\nu(ij)$ denote the number of events obtained by integrating the decay rate for a beon decaying semileptonically into the channel $h_i \ell^+ \nu_\ell$ at an instant which will be identified as $t_i = 0$ and the other beon decaying into the channel $h_j \ell^+ \nu_\ell$ at any subsequent instant $t_j = \tau > 0$

$$\nu(ij) \equiv \int_0^\infty \text{Rate } (h_i \ell^+ \nu_\ell \ , \ t_i = 0 \ ; \ h_j \ell^+ \nu_\ell \ , \ t_j = \tau) \ d\tau \ ; \tag{4}$$

similarly for the decays into channels $\tilde{i}$ and $\tilde{j}$ we have

$$\nu(\tilde{i}\tilde{j}) \equiv \int_0^\infty \text{Rate } (\bar{h}_i \ell^- \bar{\nu}_\ell \ , \ t_{\tilde{i}} = 0 \ ; \ \bar{h}_j \ell^- \bar{\nu}_\ell \ , \ t_{\tilde{j}} = \tau) \ d\tau \ . \tag{5}$$

Henceforth, for notational brevity we omit listing the leptons and use the label i of the hadron h_i to identify the *channel* itself, it being understood that the lepton pair $(\ell^+ \nu_\ell)$ accompanies the channel index that has no tilde (i) and the conjugate pair $(\ell^- \bar{\nu}_\ell)$ accompanies the channel index that has a tilde $(\tilde{i})$; also the decay to the channnel indexed by the first label always occurs prior to the decay indexed by the second label.

One can immediately envisage an asymmetry by exploiting the difference between the numbers $\nu(ij)$ and $\nu(ji)$; in the case of a single decay channel the difference will have to be between $\nu(i\tilde{i})$ and $\nu(\tilde{i}i)$. Such asymmetries were constructed earlier for specific lepton charges [4, 5]. In what follows

we combine the production of dilepton events having both (++) and (−−) signs; the resulting asymmetries are more sensitive to the presence of r_i than the previous ones.

We consider the $B^0\bar{B}^0$ pair (at a B factory) decaying into exclusive channels i and j and their conjugates $\tilde{i}$ and $\tilde{j}$. From the time-ordering of the two decays, one can measure $\nu(ij)$ and $\nu(\tilde{i}\tilde{j})$ and get the number of events having either (++) or (−−) dileptons

$$N_{ij} = \nu(ij) + \nu(\tilde{i}\tilde{j}) \ . \tag{6}$$

We can therefore form the time asymmetry

$$\alpha(ij) = \frac{N_{ij} - N_{ji}}{N_{ij} + N_{ji}} \ . \tag{7}$$

By regarding the parameters r_i , r_j and the CP-violation parameter $(|p|^2 - |q|^2)$ to be small, and keeping terms up to first order of smallness, we obtain

$$\alpha(ij) = -\frac{2y}{1-a} \ \mathrm{Re}(r_i - r_j) \ , \tag{8}$$

where the symbols have their usual meaning

$$a = \frac{1-y^2}{1+x^2} \ , \quad x = \frac{2(m_2 - m_1)}{\Gamma_2 + \Gamma_1} \ , \quad y = \frac{\Gamma_2 - \Gamma_1}{\Gamma_2 + \Gamma_1} \ . \tag{9}$$

Using the available experimental value $x = 0.73 \pm 0.05$ [6] and assuming that $|y| \ll x$, we see that (ignoring errors)

$$\alpha(ij) \simeq -5.8 \ y \ \mathrm{Re}(r_i - r_j) \ . \tag{10}$$

Obviously if experiment shows that α is nonvanishing, at least one of the parameters r_i or r_j must be nonzero, showing a breakdown of $\Delta B = \Delta Q$ rule in neutral beon decays. The case $\alpha = 0$ does not lead to a unique conclusion.

The above parameter combination can also be determined by an asymmetry which involves the oppositely-charged dilepton events [4], but that will be much less sensitive than $\alpha(ij)$

$$\mathcal{A}_{\ell^+\ell^-}(i\tilde{j} + \tilde{i}j) \ = \ -\frac{2y}{1+a} \ \mathrm{Re}(r_i - r_j) \ , \tag{11}$$

$$\simeq \ 0.21 \ \alpha(ij) \ . \tag{12}$$

The appearance of the small factor 0.21 is easily understood: while the like-sign dileptons arise due to $B\bar{B}$ mixing, the opposite-sign ones can occur even without mixing and that makes the total number (denominator) large [7].

A nontrivial variant of N_{ij} is obtained by choosing the opposite time-ordering for the $(--)$ dilepton events

$$N'_{ij} = \nu(ij) + \nu(\tilde{j}\tilde{i}) \ . \tag{13}$$

The corresponding asymmetry (obtained by replacing N in Eq. (7) by N') leads to the determination of another combination of parameters :

$$\begin{aligned} \alpha'(ij) &= -\frac{2ax}{1-a} \ \mathrm{Im}(r_i - r_j) & (14) \\ &\simeq -2.7 \ \mathrm{Im}(r_i - r_j) \ . & (15) \end{aligned}$$

This asymmetry is interesting as it is not suppressed by the factor y, but requires CP violation in the corresponding decay amplitudes. It is worth mentioning that the asymmetry $\mathcal{A}_{\ell^+\ell^-}(i\tilde{i})$ associated with unlike-sign dileptons from a single channel [5]

$$\mathcal{A}_{\ell^+\ell^-}(i\tilde{i}) = \frac{4ax}{1+a} \ \mathrm{Im}(r_i) \ \simeq 1.1 \ \mathrm{Im}(r_i) \ , \tag{16}$$

is far simpler than the above; but its comparison with α' is not meaningful because the latter involves the parameter-difference $(r_i - r_j)$.

Lastly, a comment on the effort involved in measuring the above parameters at a B factory [2] is in order. The average number of events containing same-sign dileptons due to the two exclusive decay modes $(h_i^{\mp}\ell^{\pm}\nu)$ and $(h_j^{\mp}\ell^{\pm}\nu)$ is given by

$$N_{ij}^T = \frac{1}{2} \ \mathcal{L} \ \sigma \ \chi_d \ \epsilon_i \ \epsilon_j \ f_i \ f_j \ T \ , \tag{17}$$

Here $\mathcal{L}$ ($\simeq 10^{34}$ cm^{-2} s^{-1}) is the luminosity, σ ($\simeq 1.2$ nb) is the $\Upsilon(4S)$ production cross section, factor (1/2) restricts us to neutral beon pairs, and the $B_d\bar{B}_d$ mixing ratio χ_d ($= 0.175 \pm 0.016$, see ref. [6]) gives us the event fraction with like-sign dileptons, and T is the running time. We shall consider the interesting case of $h_i = D$ and $h_j = D^*(2010)$ for which the branching fractions are $f_i \simeq 4\%$ and $f_j \simeq 9\%$ (combining the e and μ modes) [6]; for detection efficiencies (inclusive of the D and D^* branching fractions to decay into modes convenient for reconstruction) we shall take as typical values $\epsilon_i \simeq \epsilon_j \simeq 0.02$. Taking T to correspond to one full year of working we see that the total number of likesign dilepton events will be only $N_d \sim 48$.

In general for an asymmetry A the number difference δN between two types of events is given by the relation $\delta N = AN$, where N is the total sample size. We require δN to be larger than the

usual Poisson fluctuation $\sqrt{N}$ (at 1 standard deviation level). However in practice it may not be easy to meet with this condition and a small sample of events may only serve to place an upperlimit on the asymmetry $A < 1/\sqrt{N}$, or, a 90% confidence level upper limit $A < (1.64/\sqrt{N})$. Thus with the numbers mentioned above, one might envisage setting the 90% CL limits $|y\ \mathrm{Re}(r_i - r_j)| \leq 4\%$ by using Eq. (8) and $|\mathrm{Im}(r_i - r_j)| \leq 9\%$ by using Eq. (14).

In summary, we suggest the measurement of CP-conserving asymmetry Eq.(8) and CP-violating asymmetry Eq.(14) to test the validity of the $\Delta B = \Delta Q$ rule in semileptonic decays of neutral bottom mesons.

References

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[1] For a review, see, e.g., Y. Nir and H. R. Quinn, Annu. Rev. Nucl. Part. Sci. **42**, 211 (1992), and J. L. Rosner, in *B DECAYS* , edited by S. Stone (World Scientific, 2nd ed. 1994), p. 470.

[2] The BaBar collaboration: D. Boutigny *et al.*, SLAC-443, June 1994; The BELLE collaboration: M. T. Cheng *et al.*, KEK Report 94-2, April 1994.

[3] T. Goto, N. Kitazawa, Y. Okada and M. Tanaka, Phys. Rev. **D53**, 6662 (1996).

[4] G. V. Dass and K. V. L. Sarma, Phys. Rev. Lett. **72**, 191 (1994); (E) **72**, 1573 (1994).

[5] K. V. L. Sarma, Pramana - J. Phys. Supplement, **41**, 235 (1993).

[6] Particle Data Group, R. M. Barnett *et al.*, Phys. Rev. **D54**, 1 (1996).

[7] When the parameter a is tiny, as in the case of neutral K mesons ($a \simeq 0.0036$) and also most likely in the case of B_s mesons ($a \simeq 0.01$), the asymmetries of Eq. (8) and Eq. (11) will be nearly equal. It may then be prudent to combine the like-sign and unlike-sign dilepton events $\hat{N} = \nu(ij) + \nu(\tilde{i}\tilde{j}) + \nu(i\tilde{j}) + \nu(\tilde{i}j)$; the corresponding asymmetry $(-2y\ \mathrm{Re}[r_i - r_j])$, which is the result of replacing N in Eq. (7) by $\hat{N}$, does not involve the parameter a.